**RESPONSES TO AUGUST 11, 2014 – SUPPLEMENTAL INTERROGATORIES**
**UTAH LLRW DISPOSAL LICENSE RML UT 2300249**
**CONDITION 35 COMPLIANCE REPORT**

**August 18, 2014**

**For**
**Utah Division of Radiation Control**
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ENERGYSOLUTIONS

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# 1. INTRODUCTION

Energy*Solutions*, headquartered in Salt Lake City, Utah is a worldwide leader in the safe recycling, processing and disposal of nuclear material, providing innovations and technologies to the U.S. Department of Energy (DOE), commercial utilities, and medical and research facilities. At its Clive Facility, located 75 highway miles west of Salt Lake City, Energy*Solutions* operates a commercial treatment, storage and disposal facility for Class A low-level radioactive waste and Class A low-level mixed waste.

Historically, Energy*Solutions'* authorization for disposal of depleted uranium (DU) was approved by the Utah Division of Radiation Control at a concentration of 110,000 pCi/g beginning with License amendment 2 of Utah Radioactive Material License UT2300249, (approved December 3, 1990). This concentration was later increased to the specific activity of depleted uranium; i.e., pure form; with approval of the Performance Assessment submitted in support of the October 22, 1998 License renewal (limiting the depleted uranium within a container to no greater than 370,000 pCi/g, upon receipt). Under this License authorization, approximately 18,400 Ci of depleted uranium were safely disposed at Clive between 1990 and 2010.

In 2010, the Utah Radiation Control Board initiated rulemaking to require a site-specific analysis before authorizing the disposal of additional large quantities of depleted uranium. This rulemaking also applies to 3,577 metric tons (5,408 drums) of uranium trioxide ($DUO_3$) waste received by Energy*Solutions* from the Savannah River Site (SRS) in December 2009. In compliance with the depleted uranium Performance Assessment prerequisite, Energy*Solutions* is temporarily holding these drums in storage (awaiting Director approval of this depleted uranium Performance Assessment). In the future, Energy*Solutions* is also considering disposal of significant quantities of depleted uranium from the gaseous diffusion plants at Portsmouth, Ohio and Paducah, Kentucky.

As is illustrated in Figure 1-1, Energy*Solutions* is evaluating a new Federal Cell, using an evapotranspirative cover design, as the ultimate destination for significant quantities of depleted uranium. As initially submitted in 2009, the Federal Cell was named the "Class A South" cell, with a revised application and completeness review response package dated June 9, 2009 (Energy*Solutions*, 2009). Energy*Solutions*' records show that the Division indicated interrogatories on this design were under preparation, but not received prior to its withdrawal on May 2, 2011. The former Class A South cell included a clay isolation barrier as well as a proposed system for monitoring groundwater beneath this barrier; in order to differentiate the source of any potential groundwater contamination as being from Class A or 11e.(2) wastes. The former Class A South cell design was subjected to these additional buffer zone and monitoring requirements due to long-term stewardship being split between the State of Utah and DOE. The Federal Cell will be entirely within DOE stewardship and be physically and hydrologically separate from Energy*Solutions'* Class A West embankment; therefore, the additional requirements will not apply.

**Figure 1-1, Energy*Solutions*' Proposed Federal Cell Location**

On June 1, 2011, (in compliance with Condition 35.B of its Radioactive Material License UT2300249), Energy*Solutions* submitted to the Division the Report, "*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*," documenting the depleted uranium Performance Assessment. In response, Energy*Solutions* received on October 25, 2013 from the Utah Department of Environmental Quality "*Task 1: Preliminary Completeness Review.*" Following examination of the Preliminary Completeness Review, Energy*Solutions* submitted revision 1 of its depleted uranium Performance Assessment Report titled, "*Utah Low-Level Radioactive Waste Disposal License (RML UT2300249) – Condition 35 Compliance Report*," (Energy*Solutions*, 2013a).

On February 28, 2014, Energy*Solutions* received Round 1 Interrogatories from the Division, requesting clarification and additional information to support the Division's continued review of Energy*Solutions'* depleted uranium Performance Assessment. As a result of ongoing research Energy*Solutions* has conducted regarding cover design and in review of the Round 1 Interrogatories, Energy*Solutions* revised the initial design of the Federal Cell to include an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment. As a result, Energy*Solutions* created version 1.2 of its depleted uranium Performance Assessment GoldSim model. In parallel to constructing the revised GoldSim model to address the performance of the evapotranspirative cover, Energy*Solutions* submitted responses on March 31, 2014 to the Round 1 Interrogatories. Version 1.199 of the depleted uranium Performance Assessment GoldSim model was provided to DEQ reviewers on May 2, 2014 with an update to version 1.2 provided on May 15, 2014.

On May 27, 2014, Energy*Solutions* received Round 2 Interrogatories from the Division, requesting additional clarification from some of the responses provided to the Round 1 Interrogatories. Energy*Solutions* submitted responses on June 17, 2014 to the Round 2 Interrogatories. On July 1, 2014, Energy*Solutions* received Round 3 Interrogatories from the Division, requesting additional clarification for version 1.2 of the Modeling Report (and its associated appendices). Energy*Solutions* responded to the Round 3 Interrogatories on July 8, 2014.

Subsequent to responding to the three rounds of Interrogatories, the Division and Energy*Solutions* participated in several phone conferences with Dr. Craig Benson (principal technical contributor to NRC's guidance on engineered cover systems - NUREG/CR-7028). As result of these meetings, additional ten clarifications were requested from Energy*Solutions* on August 11, 2014. Responses to these supplemental interrogatories are included in Section 2.

## 2. RESPONSES TO AUGUST 11, 2014 – SUPPLEMENTAL INTERROGATORIES

As part of the review and response preparation for the Round 1 Interrogatories, Energy*Solutions* revised the design of the Federal Cell to an evapotranspirative cover equivalent to that currently under review by the Division for construction on the Class A West Embankment (examined in version 1.2 of the DU PA Model). The Division's review of Energy*Solutions'* Round 1 responses resulted in a second round of interrogatories (which were responded to on June 17, 2014). Following delivery of the Round 2 Interrogatories to Energy*Solutions*, the Division proceeded to review version1.2 of the Modeling Report (which documented the performance of the Federal Cell with evapotranspirative cover) and generate Round 3 Interrogatories specifically targeting the revised Model. Responses to the Round 3 revised Model Interrogatories were provided to the Division on July 8, 2014.

Subsequent to responding to the three rounds of Interrogatories, the Division and Energy*Solutions* participated in several phone conferences with Dr. Craig Benson (principal technical contributor to NRC's guidance on engineered cover systems - NUREG/CR-7028). As result of these meetings, additional ten clarifications were requested from Energy*Solutions* on August 11, 2014. Responses to these supplemental interrogatories are presented below.

### 1. SUPPLEMENTAL INTERROGATORY COMMENT 1

Demonstrate why 20 HYDRUS are sufficient to capture the parameter uncertainty.

***<u>EnergySolutions' Response</u>:*** Three parameters were varied at random across the HYDRUS runs, and hence formed the basis for the regression modeling (model abstraction). These were van Genuchten's $\alpha$ and *n* in the surface soil layer, and saturated hydraulic conductivity ($K_s$) in the radon barriers. Initial inspection of preliminary HYDRUS runs indicated that these three parameters (variables) were most likely to influence the resulting water contents and infiltration into the waste layer. These three inputs were varied in the HYDRUS runs – the input values for each HYDRUS run were drawn from data distributions extracted from summary statistics from the Rosetta database. This created a set of 20 observations that contained both inputs (explanatory or independent variables in a regression) and outputs (dependent variables or outputs of interest from the HYDRUS runs, which included water content in the upper five layers and infiltration into the waste layer).

The inputs to HYDRUS for these three variables were drawn at random from distributions implied by the summary statistics for the Rosetta data for Genuchten's $\alpha$ and *n*, and from values published in Benson et al. (2011) and the Energy*Solutions* design specification for $K_s$.

The Rosetta data were assumed to represent essentially points in time and space (rather than large spatial or temporal domains), hence the fitted distributions also represent points in time and space.

$$alpha = 10^{A}, where\ A \sim Normal(mean: -1.79, sd: 0.64)$$
$$n = 10^{N}, where\ N \sim Normal(mean: 0.121, sd: 0.10).$$

The $K_s$ values for the radon barriers were sampled from developed distributions where the minimum value of 4E-3 cm/day is the design specification for the upper Radon barrier (Whetstone 2011), the 50th percentile is 0.691 cm/day (2011, Section 6.4, p. 6-12; [7.5E-8 m/s rounded to 8E-8 m/s]), and the 99th percentile value of 51.8 cm/day is from a range of in-service ("naturalized") clay barrier Ksats described by Benson et al. (2011, Section 6.4, p. 6-12 [6E-6 m/s]). A lognormal distribution is fit to the 50th and 99th percentiles, and the minimum value of 4E-3 cm/day is used as a shift. Note that the minimum value was not used to fit the distribution, but simply to constrain the distribution by not allowing Ks values smaller than that. The minimum value corresponds roughly to the 0.005th quantile of the unshifted distribution, implying that a value of 0.00864 corresponds to the 0.005th quantile of the shifted distribution.

$$Ksat \sim Lognormal(geom.mean: 0.691, geom.sd: 6.396), \text{ with right shift of 0.00432}$$

The distributions for Genuchten's $\alpha$ and *n* were scaled in the Clive DU PA v1.2 GoldSim model to reflect the more coarse nature of the GoldSim cell structure. Scaling is essentially an averaging process in this context, although simple averaging is only appropriate if the immediate response is (approximately) linear to changes in the inputs. The Rosetta data based indicates that 28 data points were used to develop the summary statistics for the silty-clay soil texture. Consequently, the standard deviations in log10 space were divided by the square root of 28. A similar adjustment was not made to the distribution for $K_s$ because there was insufficient information on the number of data points that contributed to the input values (the two from Benson et al. (2011) and the design specification). Consequently, the distribution for $K_s$ in the Clive DU PA model is probably spread too much.

The issue of Interrogatory Comment 1 is the sufficiency of the 20 HYDRUS runs. These runs used inputs from distributions that were not scaled beyond the framework of points in time and space. The 1-D HYDRUS cell structure is essentially 5ft deep divided into 1,000 layers. Each layer is quite large in the remaining 2 dimensions, but, nevertheless, the HYDRUS runs were performed without spatio-temporal scaling.

Given the scaling that is appropriate for the Clive DU PA model, in effect the range of the inputs to HYDRUS are much greater than the range used in the Clive

DU PA model for the Genuchten's α and *n* parameters (by a factor of the square root of 28). This has the effect of smoothing across the range of the parameters of interest in the Clive DU PA model, but was considered a reasonable approach assuming that the regression implied by the HYDRUS runs could be used directly across a smaller range of values in the Clive DU PA model. Because of this difference in scaling, 20 HYDRUS runs are considered sufficient to support the Clive DU PA v1.2 model.

In addition, the resulting water contents and infiltration rates in the Clive DU PA model seem reasonable given the conceptual model for the ET cap (see responses to Comments #7 through #9).

## 2. SUPPLEMENTAL INTERROGATORY COMMENT 2

The Table 9 HYDRUS parameters do not appear to "bound" the α, *n*, and $K_{sat}$ distributions. For example, in the distribution $K_{sat}$ ranges from 0.0043 to 52 cm/day, but in the 20 HYDRUS runs $K_{sat}$ only ranged from 0.16 to 10.2 cm/day.

***<u>EnergySolutions' Response</u>****:* As described in response to Comment #1, the three inputs parameters (variables) were randomly drawn from input distributions for the 20 HYDRUS runs. The distributions are repeated here:

$$alpha = 10^{A}, where\ A \sim Normal(mean{:}\ -1.79, sd{:}\ 0.64)$$
$$n = 10^{N}, where\ N \sim Normal(mean{:}\ 0.121, sd{:}\ 0.10).$$
$$Ksat \sim Lognormal(geom.mean{:}\ 0.691, geom.sd{:}\ 6.396), \text{ with right shift of 0.00432}$$

The HYDRUS input values for each of the 20 runs are provided in file "CHB#6, Hydrus params and results.xlsx". Obviously the minimum and maximum for the van Genuchten α and *n* parameters is 0 and infinity, respectively, in which case random draws from those distributions will fall within their natural limits. Note also that the van Genuchten α and *n* parameter distributions in the Clive DU PA v1.2 GoldSim model are considerably narrower than the distributions from which the 20 HYDRUS inputs for these parameters were obtained (see response to Comment #1).

The same is also true for the random draws for $K_s$ – they must fall within the limits of the distribution, which are 0.00432 and infinity (although GoldSim requires setting a default to a very large number at the top end). The range of the information used to specify the distribution was, as stated in the Comment above, 0.00432 to 52 cm/day. However, the lognormal distribution was fit without using the value of 0.00432 – this value was used only to constrain the lower end of the distribution after fitting the other two values (52 and 0.07 cm/day).

Twenty observations are drawn at random from the distribution for $K_s$. These randomly drawn values range from 0.16 to 10.2 cm/day, with a mean of 2.28

cm/day, again as noted in the Comment above. These values are considered sufficiently extreme to evaluate the influence of $K_s$ on the HYDRUS model outputs, and hence to determine the influence of $K_s$ on the water content and infiltration model outputs. Note that $K_s$ is not a predictor of the HYDRUS infiltration endpoint in either the linear or quadratic regressions (that is, it is not close to statistical significance, and has a correlation of negative 0.10 with infiltration). $K_s$ was, however, included in the regression models for water content in the upper layers, and these regression models were used in the Clive DU PA v1.2 GoldSim model. It was shown very clearly in the sensitivity analysis for the Clive DU PA v1.2 GoldSim model that $K_s$ is not a sensitive parameter for any of the PA model endpoints.

## 3. SUPPLEMENTAL INTERROGATORY COMMENT 3

Benson (2011) gives the "*in-service hydraulic conductivity*" as ranging from $7.5\times10^{8}$ to $6.0\times10^{6}$ m/s [0.7 to 52 cm/day], with a mean of $4.4\times10^{7}$ m/s [3.8 cm/day]. Instead of using the provided distribution (i.e., log-triangular with a minimum, maximum, and most likely), ES/Neptune constructed a lognormal distribution with a mean and standard deviation of 0.691 and 6.396 cm/day, respectively. Provide the justification for this approach. For example, the selection of 0.0043 cm/day as the lower end of the $K_{sat}$ distribution requires justification (Appendix 5, p.41). It is not clear why a design parameter value should be used when adequate field data are available. We believe that use of the design parameter biases the $K_{sat}$ distribution in a non-conservative manner.

***EnergySolutions*' *Response***: Please see Response to Comments #1 and #2. The lognormal distribution was not fit with the value of 0.0043 – this value was used to truncate the distribution after fitting so that lower values could not be drawn at random.

Note that the Division has not provided a reference to the cited log-triangular distribution. In fact, a log-triangular distribution with a minimum of 0.7 cm/day, a maximum of 52 cm/day, and a mean of 3.8 cm/day is not possible to formulate. The mean of a log-triangular distribution is defined as:

$$\mu = \frac{2}{d_1}\left\{a + b\left[\ln\left(\frac{b}{a}\right) - 1\right]\right\} + \frac{2}{d_2}\left\{c + b\left[\ln\left(\frac{b}{c}\right) - 1\right]\right\}$$

where:

$$d_1 = \ln\left(\frac{c}{a}\right)\ln\left(\frac{b}{a}\right) \text{ and}$$

$$d_2 = \ln\left(\frac{c}{a}\right)\ln\left(\frac{c}{b}\right)$$

and, c is the maximum, b is the mode and a is the minimum.

As b approaches a, the first term above approaches zero, and the second term approaches a constant. If a = 0.7 and c = 52, then the mean approaches approximately 5.2 as b approaches a. Hence, 3.8 cannot be a mean value of a log-triangular distribution that ranges from 0.7 to 52.

If instead, the value of 3.8 is interpreted as the mode of the log-triangular distribution, then the log-triangular (0.7, 3.8, 52) distribution has a mean of 7.7, which seems greater than intended. Either way, the log-triangular suggested does not match the intent.

In addition, in principle, there are concerns with using artificially truncated distributions, and distributions with non-continuous modes. The suggested log-triangular admits values of 0.7 and 52, but 0.69999 and 52.000001, etc. are not possible values. This does not represent practical application or intuitive sense. In addition, if data are collected and the initial distribution is updated with the data in a Bayesian context, then the data cannot update the bounds of the triangular, no matter what the data look like. Scientifically, this is not reasonable. For a stable model, Bayesian updating is how new information should be incorporated, but this approach is compromised by distributions that have artificial bounds. Also, the non-continuous mode leads to unusual behavior in the center of the distribution. The functions on either side of the mode are purely convex, which is an unusual shape to take around the center of the distribution. Note that ultimately the transport variables should represent distributions of some form of average (because of spatio-temporal scaling), in which case, as more data are collected the distribution should approach normality. It is not reasonable to have convex functions on either side of a center value such as a mode if this is the intention. In addition, the mode is not differentiable, which creates further unnecessary problems.

In addition, the mean of the lognormal distribution is about 3.9 cm/day, which is very close to the value suggested in Comment #3 (3.8 cm/day). Also, the range of the lognormal distribution exceeds the range of values suggested in Comment #3.

Finally, $K_s$ is not used in the regression equations for infiltration rate because this variable is not statistically significant, and Ks is not a sensitive parameter (variable) for any of the end points of the Clive DU PA v1.2 GoldSim model.

## 4. SUPPLEMENTAL INTERROGATORY COMMENT 4

Provide justification for using the Rosetta database, as appropriate for an engineering earthen cover.

***EnergySolutions' Response**:* The class average values of soil hydraulic function parameters for the 12 soil textural classifications in Rosetta were based on 2,134 soil samples for water retention, and 1,306 soil samples for saturated hydraulic conductivity (Schaap et al. 2001). These data were obtained from the RAWLS, AHUJA, and UNSODA databases (Schaap et al. 2001). Given the stronger economic incentive for characterizing agricultural land than for rangeland, the more extensive soils databases are derived from data obtained from agricultural lands. Soil textural classifications are determined by particle size distributions, not by land use, so these databases have utility for non-agricultural application. The database of Carsel and Parrish (1988a) recommended by the Department of Environmental Quality is also derived from agricultural data. As described in Carsel and Parrish (1988a) a soil database compiled by Carsel et al. (1988) was used to develop their hydraulic property database. The title of the Carsel et al. (1988) paper is "*Characterizing the uncertainty of pesticide movement in agricultural soils.*"

The Rosetta database is widely used and has been successful in many applications in some cases performing better than the Carsel and Parrish database. Soil hydraulic properties from both databases are provided in the HYDRUS software platforms and the choice of one over the other by the modeler is considered a matter of preference. The Nemes and Wösten database was developed for European soils so would not be preferred for applications in North America. The predictive ability of Rosetta was tested on a fine sandy loam at a site in Texas by Alvarez-Acosta et al. (2012). Rosetta was used to estimate the hydraulic conductivity without direct measurements of conductivity using soil texture, bulk density and two points on the soil water retention curve. The predicted value compared well with values of saturated hydraulic conductivity measured on undisturbed samples. The results of this test support the underlying quality of the Rosetta data.

Infiltration simulations conducted by Skaggs et al. (2004) compared water content distributions predicted using HYDRUS-2D for inputs from Rosetta and Carsel and Parrish with experimental observations. The authors concluded, "*that the predictions made with the Carsel and Parrish estimates are inferior to those obtained with ROSETTA.*"

For their work on land surface models Gutmann and Small (2007) noted that they used the Rosetta database rather than Carsel and Parrish "*because of its international nature, availability of the database to other researchers, as well as the extensive use of this database and the UNSODA database.*"

The available Unit 4 soil texture data indicate the sample represents an extreme of the range of particle sizes that compose the silty clay textural class. Distributions were developed for the van Genuchten $\alpha$ and $n$ parameters for the Surface and Evaporative zone layers that represented the entire range of the silty clay class by using the mean and standard deviation values provided by the Rosetta database.

The Benson et al. (2011) report published by the NRC (NUREG/CR-7028) report provides recommendations for ranges of hydraulic parameters that may be used to represent in-service conditions of store-and-release and barrier layers in covers. The Surface and Evaporative Zone layers in the Clive ET cover system correspond to store-and-release layers. For the infiltration modeling, values of the van Genuchten parameter alpha for these two layers were drawn from a statistical distribution with a mean of 0.016 1/cm. The value for alpha recommended for in-service layers by Benson et al. (2011, p. 10-4) is 0.2 1/kPa which corresponds to a value of 0.02 1/cm, similar to the mean used for the infiltration simulations.

The distribution used for the van Genuchten n parameter for the HYDRUS simulations had a mean of 1.32. The value for n recommended for in-service layers by Benson et al. (2011, p. 10-4) is 1.3.

A single value 4.46 cm/day based on site-specific measurement was used in the experimental design for the saturated hydraulic conductivity ($K_s$) of the Surface and Evaporative Zone layers. Mean values of the $K_s$ of store-and-release layers of in-service covers are listed in Table 6.6 of Benson et al. (2011). The geometric mean of these results is $8.7 \times 10^{-7}$ m/s or 7.5 cm/day. This value is less than twice the value used for the infiltration modeling.

The experimental design for the infiltration modeling used a $K_s$ distribution developed from a minimum value of $4\times10^{-3}$ cm/day corresponding to the design specification for the upper radon barrier (Whetstone 2007, Table 8), and 50th and 99th percentile values of 0.7 cm/day ($7.5 \times 10^{-8}$ m/s rounded to $8 \times 10^{-8}$ m/s) and 52 cm/day ($6 \times 10^{-6}$ m/s), respectively, which are from a range of in-service ("*naturalized*") clay barrier $K_s$ values described by Benson et al. (2011, Section 6.4, p. 6-12). The value for $K_s$ recommended by Benson et al (2011, p. 10-3) for modeling in-service cover layers is $5 \times 10^{-7}$ m/s which is well within the distribution used for the Clive DU PA infiltration modeling.

Single values of $\alpha$ and *n* determined from site-specific measurements were used for the radon barrier in the infiltration modeling. A value of 0.003 1/cm was used for $\alpha$ and a value of 1.17 was used for *n*. Benson et al. (2011, p. 10-4) recommend using the result from a single measurement at a single site for $\alpha$. This is a value of 0.02 1/cm. Two other values are available for sample sizes considered to be unaffected by scale for the $K_s$ measurements (Benson et al, 2011, Table 6-9). The geometric mean of the three measurements is 0.002. A range from 1.2 to 1.4 is recommended by Benson et al. (2011) for the *n* parameter. The value used for the infiltration modeling is slightly below the low end of that range.

## 5. SUPPLEMENTAL INTERROGATORY COMMENT 5

Surface boundary condition and regression equation form:

a) Provide additional explanation/justification for the assumed surface boundary condition and the sensitivity of the HYDRUS results to the boundary conditions.

b) Also, why is a linear regression the optimal surface response for the design?

***<u>EnergySolutions' Response</u>:***

a) The surface boundary conditions for the HYDRUS cover model consisted of 100 years of daily values of precipitation, potential evaporation, and potential transpiration. These boundary conditions were repeated 10 times for a 1,000 year simulation. The methods used to develop the atmospheric boundary condition file are described in detail in Section 12.3 of Appendix 5 to version 1.2 of the Modeling Report. This section includes plots of the input values produced and references to all parameters and methods.

   Sensitivity under different climate scenarios was not evaluated because there is no scientific evidence suggesting climate change in the next 10ky. As it is, as discussed in the deep time appendix, current science suggests that the future climate is likely to be drier in the next 10ky. Variability in the climate record is included, and that is considered sufficient for the likely future of the site.

   The variability in the simulated climate record matches variability in the data record. As discussed in Appendix 13 - Deep Time Assessment of version 1.2 of the Modeling Report, the climate in the area of Clive has not changed substantially in the past 10ky at least, and is not expected to change for the next 40-50ky or possibly much longer. The objective of this Clive DU PA, following Utah regulations, is to provide a probabilistic assessment of the performance of the disposal system at Clive, not to evaluate one-off cases that are considered so unlikely that they do not fall within the probabilistic bounds that are developed from available data. It is reasonable in this probabilistic system to challenge any of the probabilistic bounds, but not to perform and report one-off analyses with combinations of input values that are implausible. Whereas establishing the probabilistic bounds is always a judgment call, the variability contained in the historical data record, and the small probability of significant changes in future climate over the next 10 ky, is reflected in the modeling that has been performed. Models can always be manipulated to show specific results, but this is not the approach that has been taken for this probabilistic PA.

b) Extensive statistical analysis has been conducted to evaluate possible model abstraction from HYDRUS to GoldSim for water content in each of the five upper layers of the ET cap, and for infiltration into the waste. Three parameters were varied in HYDRUS, and hence formed the basis for the regression modeling (model abstraction). These were van Genuchten's $\alpha$ and *n* in the surface soil layers, and saturated hydraulic conductivity ($K_s$) in the two lower radon barriers. These 3 inputs were varied in the HYDRUS runs – the input values for each HYDRUS run were drawn from data distributions extracted from summary statistics from the Rosetta database. This created a set of 20 observations that contained both inputs (explanatory or independent variables in a regression) and outputs (outputs of interest from the HYDRUS runs, which included water content in the upper five layers and infiltration into the waste layer). Note that there are only five layers in the ET cover, but flux into waste is calculated as a sixth observation node located at the bottom of Radon Barrier 2.

   Regression models were run, including linear regression and quadratic regression. Results of the linear regressions are presented in Table 1, whereas results of the quadratic regressions are presented in Table 2.

   $K_s$ is not statistically significant in the linear regression models for any of the endpoints, but this variable was maintained in the linear regression models for the water content endpoints of interest. This provides the first indication that $K_s$ is unlikely to be a sensitive parameter in the Clive DU PA model. Despite the r-squared values, which are decent for at least the top two layers, the models are very weak. The dominant factors are the intercept term for all water content endpoints, a negative value of *n* for water content in the top two layers, and positive values of alpha for the other layers and the infiltration rate.

   The best quadratic fit was obtained by considering all quadratic model options and finding the best fit using stepwise regression. The quadratic regressions follow a very similar pattern. The linear term of $K_s$ is marginally significant for the radon layers, but the quadratic term is not. For the other parameters both the linear and quadratic terms for alpha and n are significant for the same models as for the linear regression. However, the quadratic terms for alpha have negative coefficients. The contribution to predicted values comes almost entirely from the intercept term for all water content endpoints. For infiltration the predicted values are driven the intercept term adjusted by a combined negative effect from both terms for *n*.

Overall, the regression models are not very good. Although the r-squared values look reasonable for some of these regression models, explanations of the regression models are difficult to provide. That is, statistical fits are reasonable, but practical explanation is difficult. Consequently, the linear regressions were used for simplicity.

**Table 1**: Linear Regression Equations

| Layer | Intercept | SE | Ksat | SE | Alpha | SE | N | SE | R^2 |
|---|---|---|---|---|---|---|---|---|---|
| Surface WC | 0.5536 | 0.0414 | -0.0020 | 0.0033 | -0.0555 | 0.1196 | -0.2225 | 0.0313 | 0.79 |
| Evap WC | 0.6836 | 0.0485 | -0.0022 | 0.0039 | -0.1565 | 0.1402 | -0.2881 | 0.0368 | 0.82 |
| Frost WC | 0.0726 | 0.0073 | 0.0002 | 0.0006 | 0.0521 | 0.0211 | 0.0000 | 0.0055 | 0.28 |
| Upper Radon WC | 0.3000 | 0.0318 | -0.0036 | 0.0026 | 0.3142 | 0.0921 | -0.0130 | 0.0241 | 0.53 |
| Lower Radon WC | 0.3000 | 0.0318 | -0.0036 | 0.0026 | 0.3142 | 0.0921 | -0.0130 | 0.0241 | 0.53 |
| Bottom WC | 0.3000 | 0.0318 | -0.0036 | 0.0026 | 0.3142 | 0.0921 | -0.0130 | 0.0241 | 0.53 |
| Infiltration Flux | 0.9590 | 0.8149 | NA | NA | 4.3971 | 2.3323 | -0.5210 | 0.5869 | 0.22 |

**Table 2**: Quadratic Regression Equations

| Layer | Intercept | SE | Ksat | SE | Ksat^2 | SE | Alpha | SE |
|---|---|---|---|---|---|---|---|---|
| Surface WC | 1.43 | 0.0704 | NA | NA | NA | NA | NA | NA |
| Evap WC | 1.66 | 0.117 | NA | NA | NA | NA | -0.0102 | 0.248 |
| Frost WC | 0.0675 | 0.0012 | NA | NA | NA | NA | 0.338 | 0.0472 |
| Upper Radon WC | 0.268 | 0.00828 | -0.0112 | 0.00457 | 0.000755 | 0.000448 | 1.56 | 0.212 |
| Lower Radon WC | 0.268 | 0.00828 | -0.0112 | 0.00457 | 0.000755 | 0.000448 | 1.56 | 0.212 |
| Bottom WC | 0.268 | 0.00828 | -0.0112 | 0.00457 | 0.000755 | 0.000448 | 1.56 | 0.212 |
| Infiltration Flux | 7.2 | 4.22 | NA | NA | NA | NA | 20.6 | 8.92 |

| Layer | Alpha^2 | SE | N | SE | N^2 | SE | R^2 |
|---|---|---|---|---|---|---|---|
| Surface WC | NA | NA | -1.5 | 0.101 | 0.443 | 0.0349 | 0.98 |
| Evap WC | -0.397 | 0.8 | -1.71 | 0.165 | 0.493 | 0.0571 | 0.95 |
| Frost WC | -0.949 | 0.152 | NA | NA | NA | NA | 0.78 |
| Upper Radon WC | -4.18 | 0.681 | NA | NA | NA | NA | 0.87 |
| Lower Radon WC | -4.18 | 0.681 | NA | NA | NA | NA | 0.87 |
| Bottom WC | -4.18 | 0.681 | NA | NA | NA | NA | 0.87 |
| Infiltration Flux | -53.3 | 28.8 | -10.1 | 5.93 | 3.35 | 2.06 | 0.54 |

"NA" represents variables that are not statistically significant. Note that sometimes statistically insignificant variables were maintained in the models.
Statistical significance can be approximated by considering twice the standard error and then comparing to the coefficient.

Predicted values for inputs values of alpha = 0.037, n = 1.34 and Ks = 2.28 are provided in Table 3 below. Note that the predicted values are not very different for the two models.

**Table 3**: Predicted values for the regression models with alpha = 0.037, *n* = 1.34 and Ks = 2.28

| Layer | Linear prediction | Quadratic prediction |
|---|---|---|
| Surface WC | 0.248242876 | 0.214500766 |
| Evap WC | 0.285917593 | 0.251728957 |
| Frost WC | 0.074856631 | 0.078703594 |
| Upper Radon WC | 0.28602206 | 0.2983984 |
| Lower Radon WC | 0.28602206 | 0.2983984 |
| Bottom WC | 0.28602206 | 0.2983984 |
| Infiltration Flux | 0.421896147 | 0.366899933 |

Although the quadratic fits are often better statistically, they are not any more useful practically. A comparison between the linear regression and quadratic regression effects on the output is shown in Figure 2 for water content of the surface layer, and in Figure 3 for the infiltration rate into the waste.

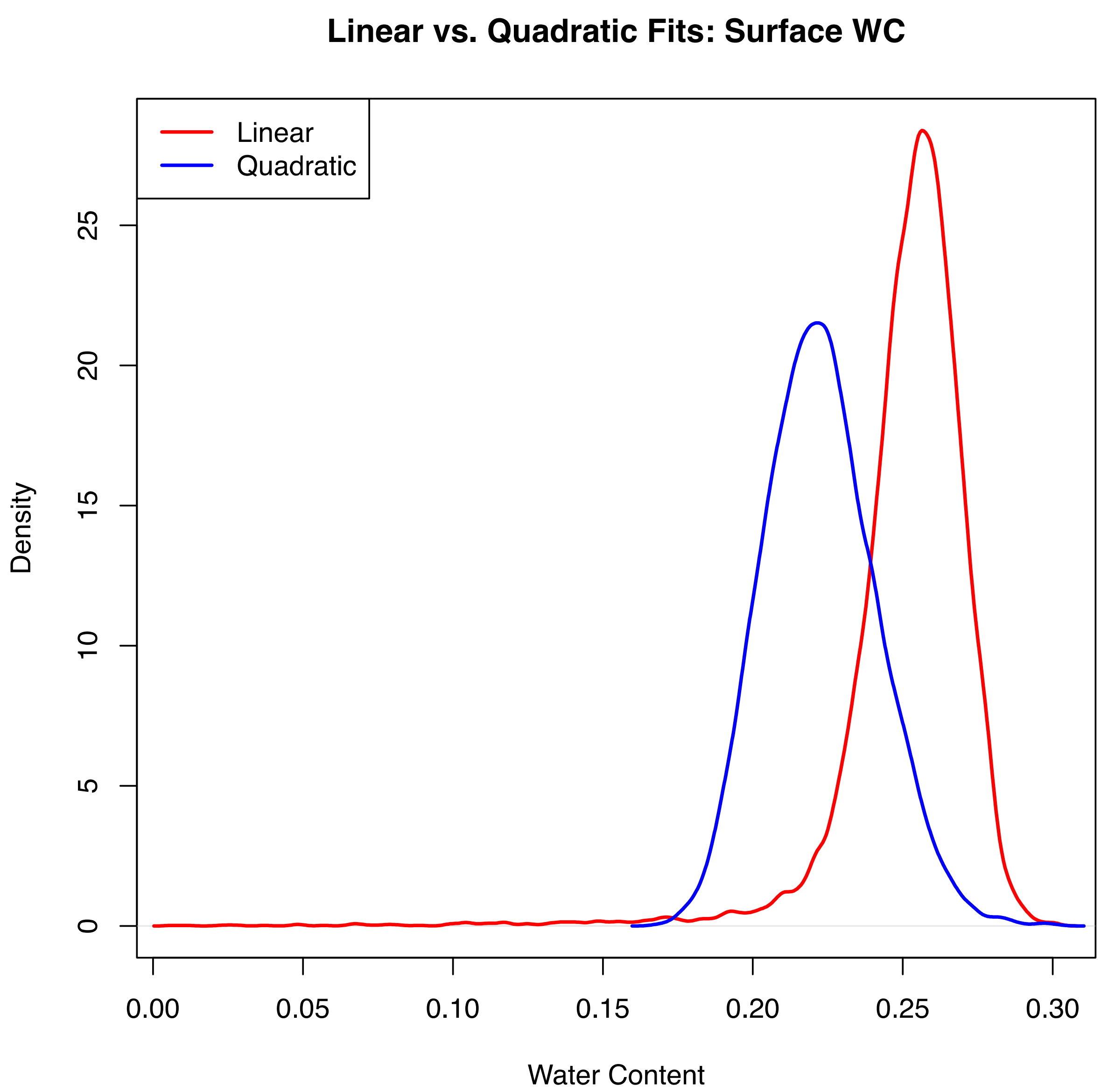



**Figure 2**: Linear and Quadratic regression predictions for the Surface layer water content.

The linear regressions for all water content endpoints show the same effect that the predicted values are greater than for the quadratic regressions. This was a significant reason for using the linear regression models over the quadratic regression models.

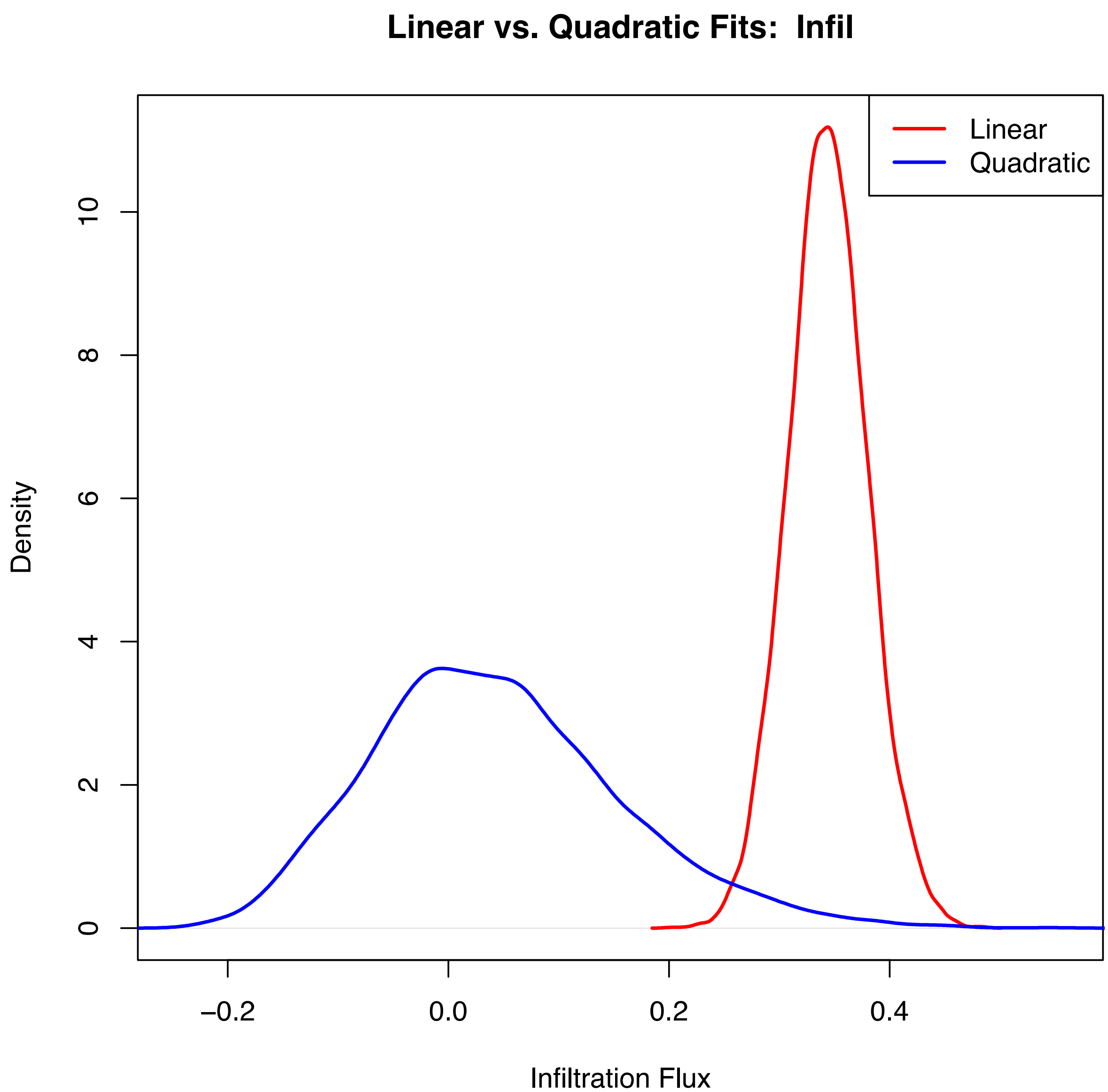



**Figure 3**: Linear and Quadratic regression predictions for the Infiltration into the waste

For infiltration, the linear regression indicated considerably greater values of infiltration flux than the quadratic regression. And, the quadratic regression implied a large proportion of negative values. Consequently the linear regression models were preferred.

## 6. SUPPLEMENTAL INTERROGATORY COMMENT 6

To summarize the 20 HYDRUS results, Appendix 5 of version 1.2 of the Modeling Report, Section 12.9 states*: Infiltration flux into the waste zone ranged from 0.007 to 2.9 mm/yr, with an average of 0.42 mm/yr, and a log mean of 0.076 mm/yr for the 20 replicates*. In addition to this statement, provide the results for each HYDRUS run so that the results can be matched to the input data.

***EnergySolutions*' Response***:* See the Excel file named "*CHB#6, Hydrus params and results.xlsx*" for infiltration and water content results matched with input data for the 20 replicates (Section 4). This file includes the 20 replicate values of van Genuchten alpha and n for the Surface and Evaporative Zone layers, and $K_{sat}$ for the radon barriers. Infiltration and water content data are calculated as averages over the last 100 years of a 1,000-year simulation (i.e. from 900 to 1000 years).

Log Infiltration versus log alpha, and versus log $K_{sat}$ are shown in Figures 1-2 in this Excel file. It is apparent from these figures that there is no correlation between infiltration and the $K_{sat}$ of the radon barriers for the 20 HYDRUS-1D replicates, but there is a correlation between infiltration and alpha of the two uppermost surface layers. There is no apparent correlation between infiltration and n of the two uppermost surface layers (Figure 3).

Volumetric water content versus log alpha, and versus log $K_{sat}$ are also shown in Figures 4 and 5 in this Excel file. It is apparent that there is a correlation between volumetric water content in the lower layers (frost protection and radon barriers) and alpha of the two uppermost surface layers. Note above that infiltration is correlated with alpha, therefore as alpha increases, infiltration increases, as does the water content of the lower layers. Volumetric water content is poorly correlated (R2 = 0.366) with $K_{sat}$ of the radon barriers as shown in Figure 5 in the Excel file. There is no apparent correlation between water content and n of the two uppermost surface layers (Figure 6). Note that in Figures 4-6, only radon barrier 1 is shown because water contents are very similar between radon barriers 1 and 2.

This file includes calculations of mean, log mean, min, and max of the 20 replicate input and output values.

## 7. SUPPLEMENTAL INTERROGATORY COMMENT 7

The HYDRUS and GoldSim calculated infiltration rates (and perhaps other intermediary results) need to be provided in the report, so that the reviewers do not have to delve into the code's output files. For example, provide dot plots of the infiltration rates through the surface layer and/or provide a statistical summary of the infiltration rates that were sampled in GoldSim.

***EnergySolutions*' *Response***: Figure 4 shows the sorted infiltration through each layer of the ET cover and into the waste zone for the 20 Hydrus-1D replicates where infiltration is the average infiltration over the last 100 years of a 1,000-year simulation. Note that there are only five layers in the ET cover, but flux into waste is calculated as a sixth observation node located at the bottom of Radon Barrier 2.

Figure 4 shows that for the first 8 of the sorted replicates, infiltration through the surface layer is over 3 orders of magnitude higher than infiltration into the waste. For the 20th replicate, infiltration through the surface layer is only about one order of magnitude higher than infiltration into the waste.

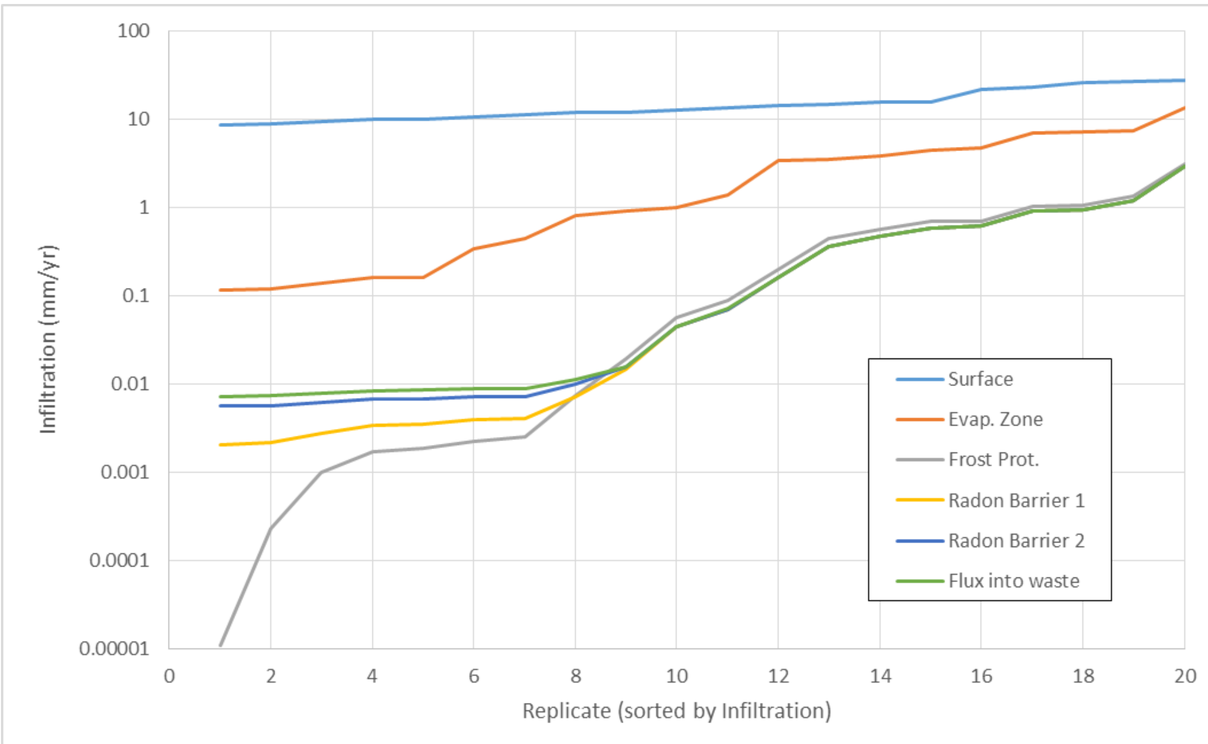



**Figure 4**. Sorted infiltration for the 20 HYDRUS-1D simulations for each layer of the ET cover.

Figure 5 shows the same result for HYDRUS-1D flux into waste presented in Figure 4, along with the infiltration into waste calculated by GoldSim DU PA Model v1.2 for 1,000 replicates using the linear regression equation where infiltration is based on van Genuchten alpha and n. It is clear in Figure 5 that GoldSim infiltration has a smaller range than the HYDRUS-1D results.

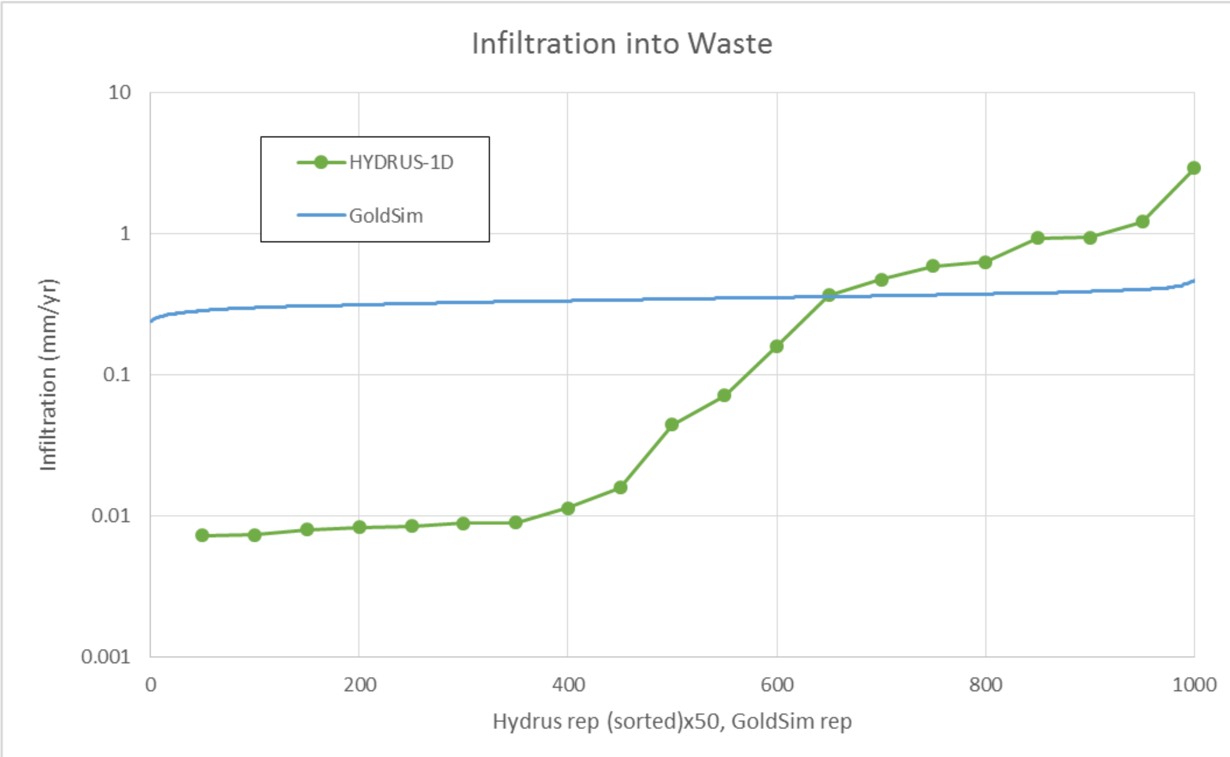



**Figure 5**. Sorted infiltration for the 20 HYDRUS-1D simulations compared to the GoldSim calculated infiltration.

(Please see Responses to Comments #1 and #2.) Values of the α and n parameters for the van Genuchten –Mualem hydraulic conductivity model used as inputs for the 20 HYDRUS simulations were drawn from distributions based on the means and standard deviations obtained for the silty clay textural class in the Rosetta database. The HYDRUS simulation results provided the volumetric water content and net infiltration estimates used to develop the regression equations that describe a response surface for calculating volumetric water content and net infiltration for values of α, n, and $K_s$ drawn from distributions in the GoldSim DU PA Model. The information in Rosetta are considered data points in time and space, which reasonably reflect the spatial scale of the HYDRUS model given the 1,000 HYDRUS layers in the 5ft column.

To provide consistency with the conceptual model, probability distributions needed to be specified that matched the spatio-temporal scale of the model. The fitted regression models were used in the Clive DU PA GoldSim model, but the distributions of alpha and n that were re-scaled to match the structure of the GoldSim model. Scaling in this way is inherently and averaging process, although some care needs to be taken to ensure that the immediate response reacts linearly to the inputs (expectation is a linear operator). The Rosetta data based indicates that 28 samples were used to develop the mean and standard deviation estimates. Consequently, scaling was performed by dividing the standard deviation by the square root of 28, which represents using the standard error of the Rosetta data for the parameter distributions implemented in GoldSim rather than the standard deviations that were used in developing the HYDRUS results. This provides an appropriate distribution for the Clive DU PA GoldSim model given the structure and scale of that model.

**The result of this up-scaling process is that the net infiltration and volumetric water content distributions are narrower in the GoldSim DU PA model than they are for the 20 HYDRUS simulations.**

Table 4 summarizes the infiltration statistics for the HYDRUS-1D and GoldSim model results where it is apparent that the mean infiltration values are similar (0.422 mm/yr for Hydrus and 0.344 mm/yr for GoldSim).

**Table 4. Infiltration Statistics for HYDRUS-1D and GoldSim Simulations.**

| **Infiltration into waste (mm/yr)** | | |
|---|---|---|
| | **HYDRUS-1D** | **GoldSim** |
| Mean | 0.422 | 0.344 |
| Log mean | 0.076 | 0.344 |
| Min | 0.007 | 0.239 |
| Max | 2.931 | 0.469 |

## 8. SUPPLEMENTAL INTERROGATORY COMMENT 8

Compare regression equation results to HYDRUS results

a) Demonstrate that the fitted equations for water content and infiltration (Appendix 5, equations 39 and 40, and Table 10) give "*reasonable*" results when compared to HYDRUS.

b) For example, provide an explanation for why $K_{sat}$ is insensitive to the infiltration rates.

***EnergySolutions' Response***:

a) The Clive DU PA Model v1.2 was used to generate 1,000 realizations of the net infiltration rate and the cover layer volumetric water contents. A comparison of maximum, minimum, means and standard deviations with the 20 HYDRUS simulation results are shown in the Table 5 below.

| Parameter | Max H1D | Max v1.2 | Min H1D | Min v1.2 | Mean H1D | Mean v1.2 | Standard Deviation H1D | Standard Deviation v1.2 |
|---|---|---|---|---|---|---|---|---|
| Net Infiltration Rate [mm/yr] | 2.931 | 0.469 | 0.007 | 0.239 | 0.422 | 0.344 | 0.703 | 0.0361 |
| Surface Layer WC | 0.374 | 0.296 | 0.172 | 0.110 | 0.248 | 0.235 | 0.0664 | 0.0213 |
| Evaporative Layer WC | 0.443 | 0.349 | 0.164 | 0.110 | 0.286 | 0.293 | 0.0840 | 0.0262 |
| Frost Protection Layer WC | 0.086 | 0.126 | 0.067 | 0.073 | 0.075 | 0.0741 | 0.0063 | 0.00249 |
| Upper Radon Barrier WC | 0.356 | 0.100 | 0.243 | 0.293 | 0.286 | 0.277 | 0.0342 | 0.027 |
| Lower Radon Barrier WC | 0.356 | 0.100 | 0.243 | 0.293 | 0.286 | 0.277 | 0.0342 | 0.027 |

The following histogram plots (Figures 6 through 11) compare results between the Clive DU PA Model v1.2 (GS) and the 20 HYDRUS simulations (H1D). For all parameters the means are comparable and the standard deviations are larger for the HYDRUS results. This difference is due to parameter scaling required for the Clive DU PA Model. As discussed in the response to Comment #1 above the distributions for Genuchten's $\alpha$ and n were scaled in the Clive DU PA v1.2 GoldSim model to reflect the more coarse nature of the GoldSim cell structure.

Scaling is essentially an averaging process in this context, although simple averaging is only appropriate if the immediate response is (approximately) linear to changes in the inputs. The Rosetta summary indicates that 28 data points were used to develop the summary statistics for the silty-clay soil texture. Consequently, the standard deviations in log10 space were divided by the square root of 28. A similar adjustment was not made to the distribution for $K_s$ because there was insufficient information on the number of data points that contributed to the input values (the two from Benson et al. (2011) and the design specification). Consequently, the distribution for $K_s$ in the Clive DU PA model is probably spread too much.

The 20 HYDRUS runs used inputs from distributions that were not scaled beyond the framework of points in time and space. The 1-D HYDRUS cell structure is essentially 5ft deep divided into 1,000 layers. Each layer is quite large in the remaining 2 dimensions, but, nevertheless, the HYDRUS runs were performed without spatio-temporal scaling.

Given the scaling that is appropriate for the Clive DU PA model, in effect the range of the inputs to HYDRUS are much greater than the range used in the Clive DU PA model for the van Genuchten's $\alpha$ and n parameters (by a factor of the square root of 28). This has the effect of smoothing across the range of the parameters of interest in the Clive DU PA model, but was considered a reasonable approach assuming that the regression implied by the HYDRUS runs could be used directly across a smaller range of values in the Clive DU PA model.

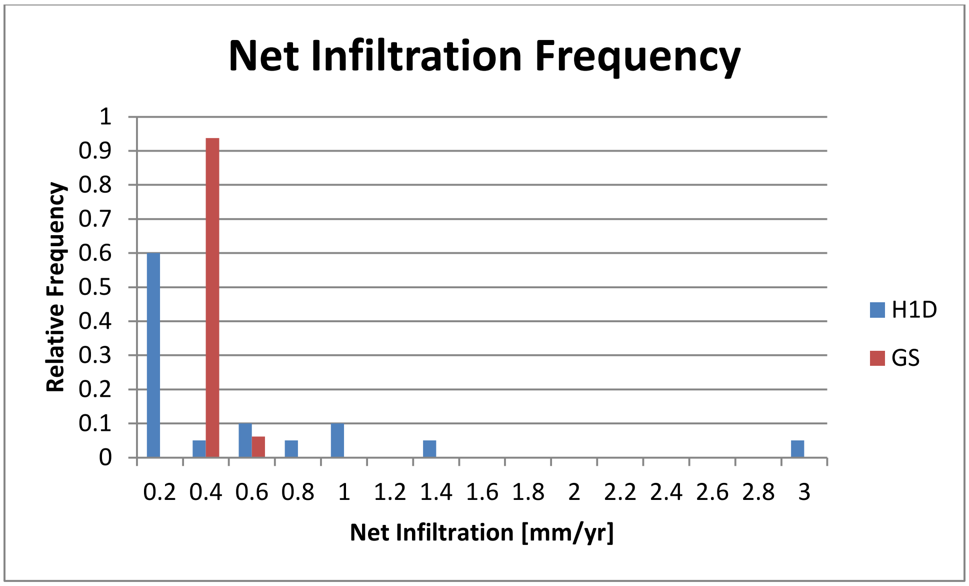



**Figure 6: Net infiltration**

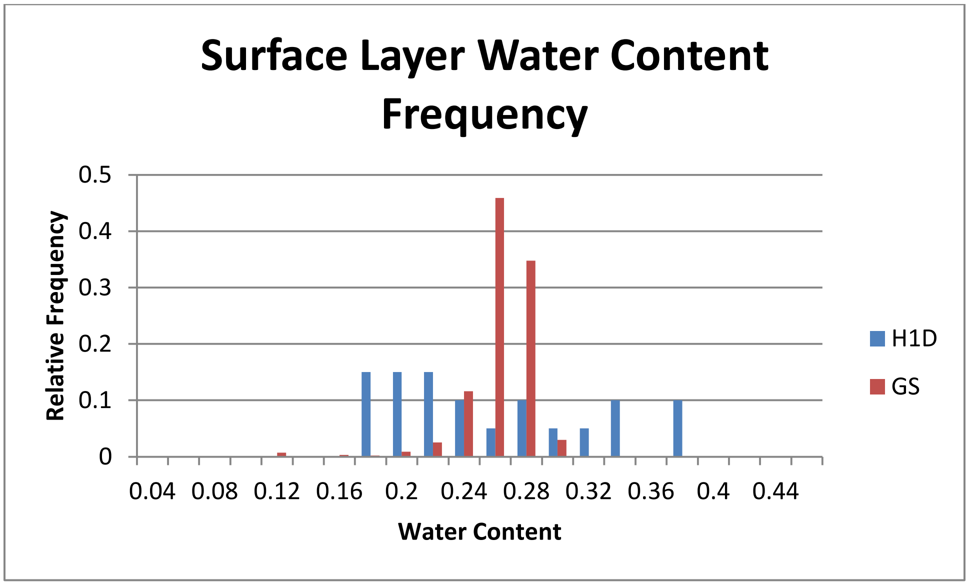



**Figure 7: Surface Layer**

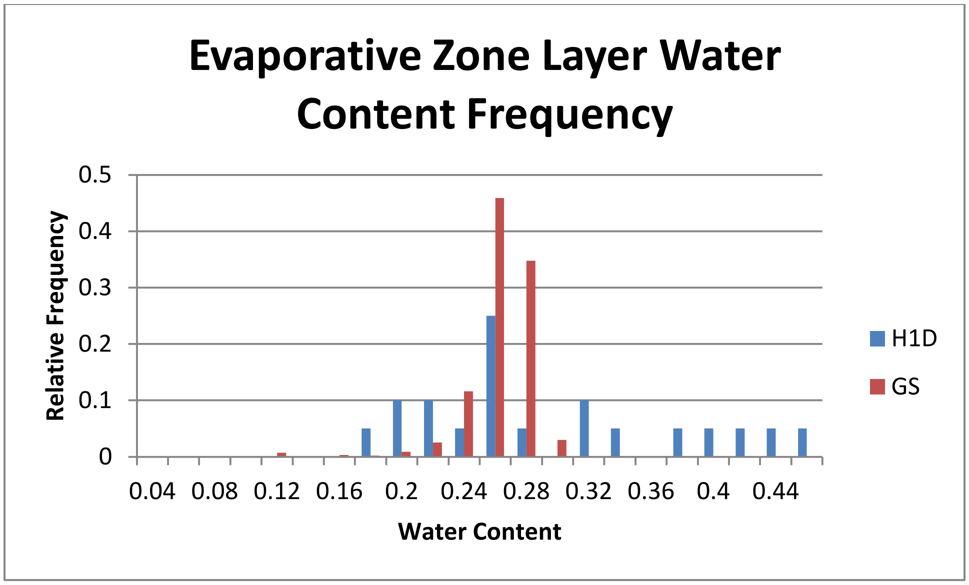



**Figure 8: Evaporative Layer**

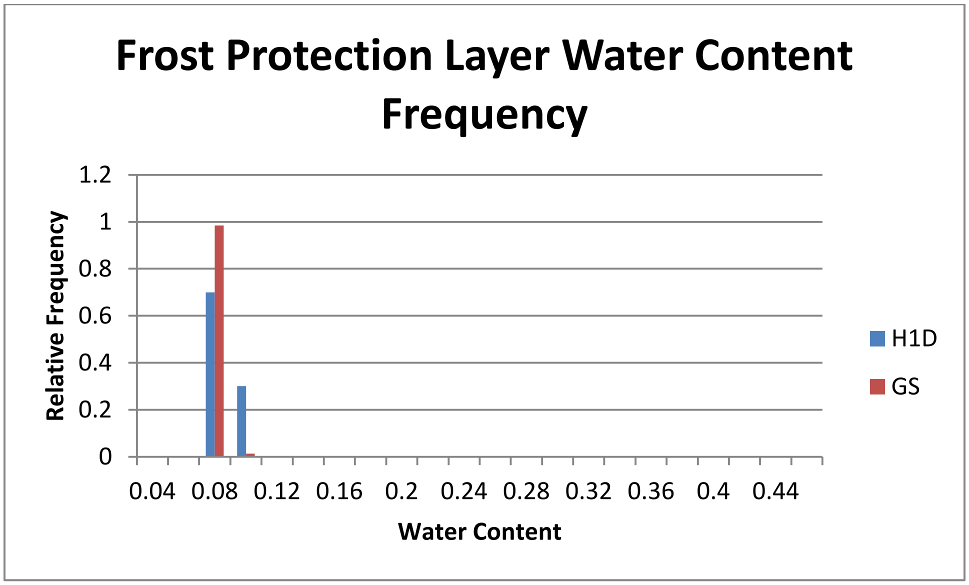



**Figure 9: Frost Layer**

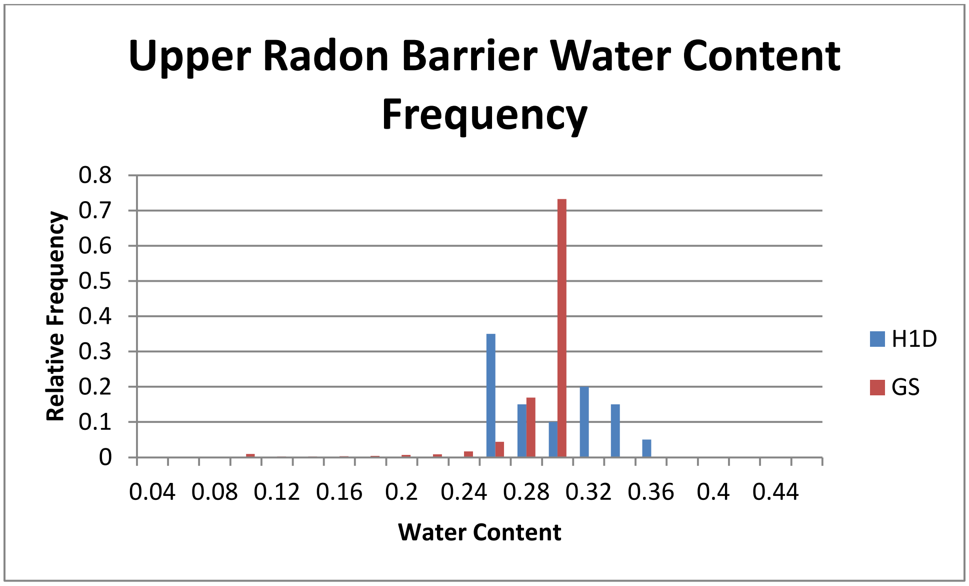



**Figure 10: Upper Radon Barrier**

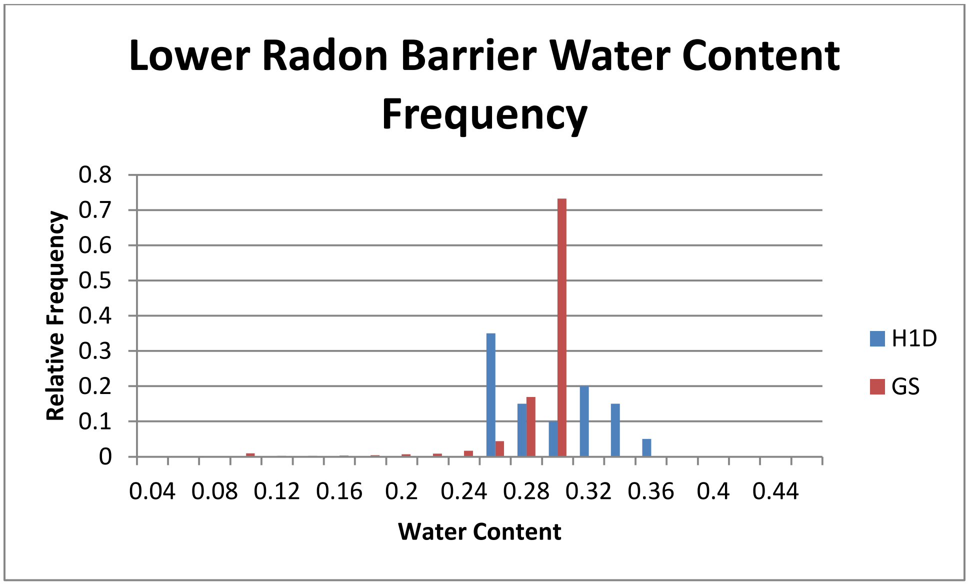
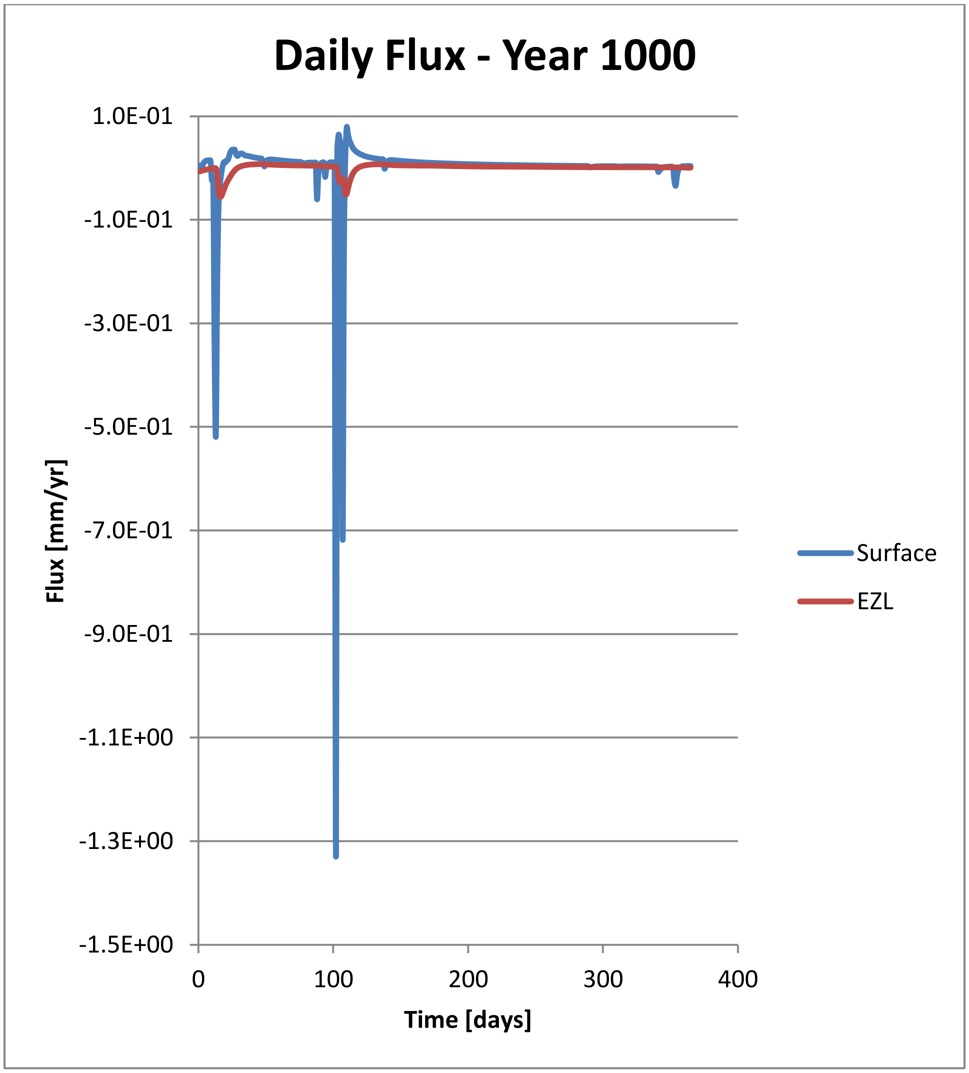
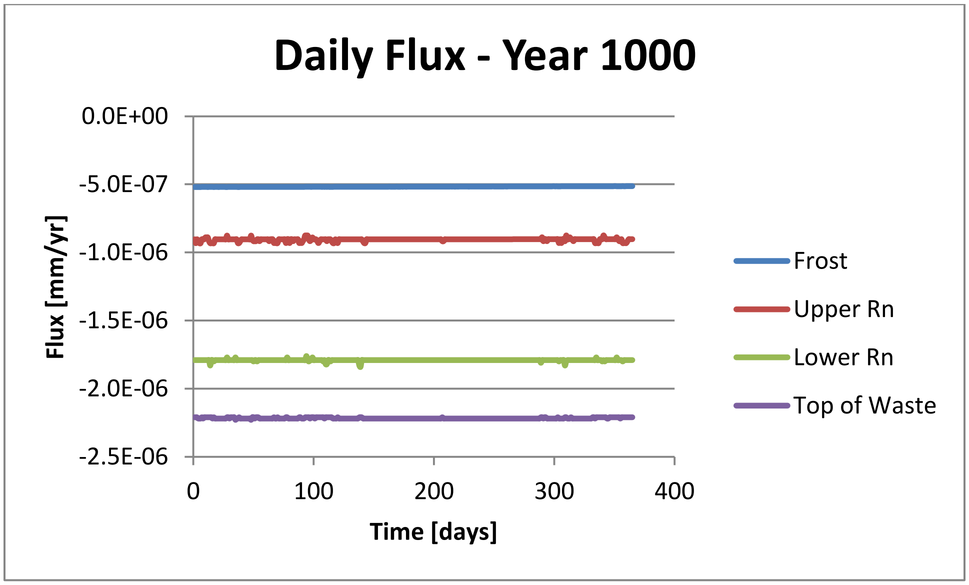



**Figure 11: Lower Radon Barrier**

b) The reason for the insensitivity of net infiltration to changes in the saturated hydraulic conductivity can be seen by examining steady-state fluxes for each layer on a daily time scale. The plots below show daily flux in each layer of the cover for the last year of the 1,000 year simulation. The surface and evaporative zone layer are shown on different plots from the other layers because of the three to four order of magnitude differences in flux as compared to the frost protection layer and the radon barriers. The simulation shown is the first of the 20 HYDRUS simulations used for the Clive DU PA Model v1.2. In the first plot large changes in flux in the surface layer are due to precipitation events with negative values corresponding to infiltration and positive values to evaporation. The magnitude of the daily variations in flux is reduced in the evaporative zone layer. Both layers serve to hold water following a precipitation event until it returns to the atmosphere through evaporation.




The next plot shows the daily flux values over the same time period for the frost protection layer, radon barriers and at the top of the waste. These fluxes are orders of magnitude smaller and show small variations. Net infiltration rates simulated by HYDRUS are likely not sensitive to the saturated hydraulic conductivity of the radon barriers because these layers do not have a large influence on the water balance of the cover system.




## 9. SUPPLEMENTAL INTERROGATORY COMMENT 9

Compare the moisture contents calculated using the fitted equations to the Bingham (1991, Table 6 and/or Appendix B) Clive site measured Unit 4 moisture contents, and rationalize any differences.

***<u>EnergySolutions</u>*' *<u>Response</u>***: Volumetric water contents calculated using the fitted equations were extracted from the GoldSim DU PA Model v1.2 by adding a result element for the Expression “WaterContentETCover_regr”. Then the model was run for 1,000 simulations to generate 1,000 values of water content for the Evaporative Zone layer (Unit 4 soil). The Surface Layer was not selected for this comparison because it has a reduced porosity due to the gravel admixture.

Gravimetric water contents for Unit 4 soils, at depths less than or equal to 2 feet (near the depth of the Evaporative Zone layer (0.5 to 1.5 ft)), were pulled from Bingham (1991, Table 6, pdf p. 42-43). Six values matched these criteria and those data are presented in Table 6. Volumetric water contents for these six samples were calculated by multiplying the gravimetric values by the bulk density of 1.397 g/cm3 reported on pdf p. 174 of Bingham (1991) for sample GW19A-B1 (Unit 4 sample).

**Table 6. Water Content Data from Bingham (1991, Table 6).**

| Bingham 1991 data | | | | | |
|---|---|---|---|---|---|
| DH ID | Sample ID | Depth (ft) | Unit | Grav.WC% | Vol. WC |
| | | | | | |
| GW-17A | L-1 | 2 | 4 | 27.8 | 0.39 |
| GW-19B | L-1 | 2 | 4 | 17.5 | 0.24 |
| SLC-203 | NA | 2 | 4 | 21.7 | 0.30 |
| SLC-204 | NA | 2 | 4 | 15.3 | 0.21 |
| SLC-205 | NA | 2 | 4 | 20.7 | 0.29 |
| SLC-206 | NA | 2 | 4 | 19.6 | 0.27 |
| | | | | | |
| Avg | | | | 20.43 | 0.285 |
| Min | | | | 15.30 | 0.214 |
| Max | | | | 27.80 | 0.388 |

Volumetric water contents from GoldSim (1000 replicates), from HYDRUS-1D (20 replicates) and the six measured values from Table 6 are shown in Figure 14. For the x-axis, each of the 6 values in Table 6 were plotted at increments of ~167 in order to show the data on the x-axis with 1,000 values (for the GoldSim results). Similarly, the HYDRUS-1D values were plotted at increments of 50. As shown in Figure 14, the volumetric water contents calculated with the fitted equation in GoldSim are well-bounded by the Bingham data from Table 6. The mean volumetric water content value in Table 6 is 0.285 while the mean from the GoldSim model 1,000 replicates is slightly higher at 0.294. The mean value of the 20 HYDRUS-1D replicates is 0.286, nearly identical to the Bingham 1991 samples.

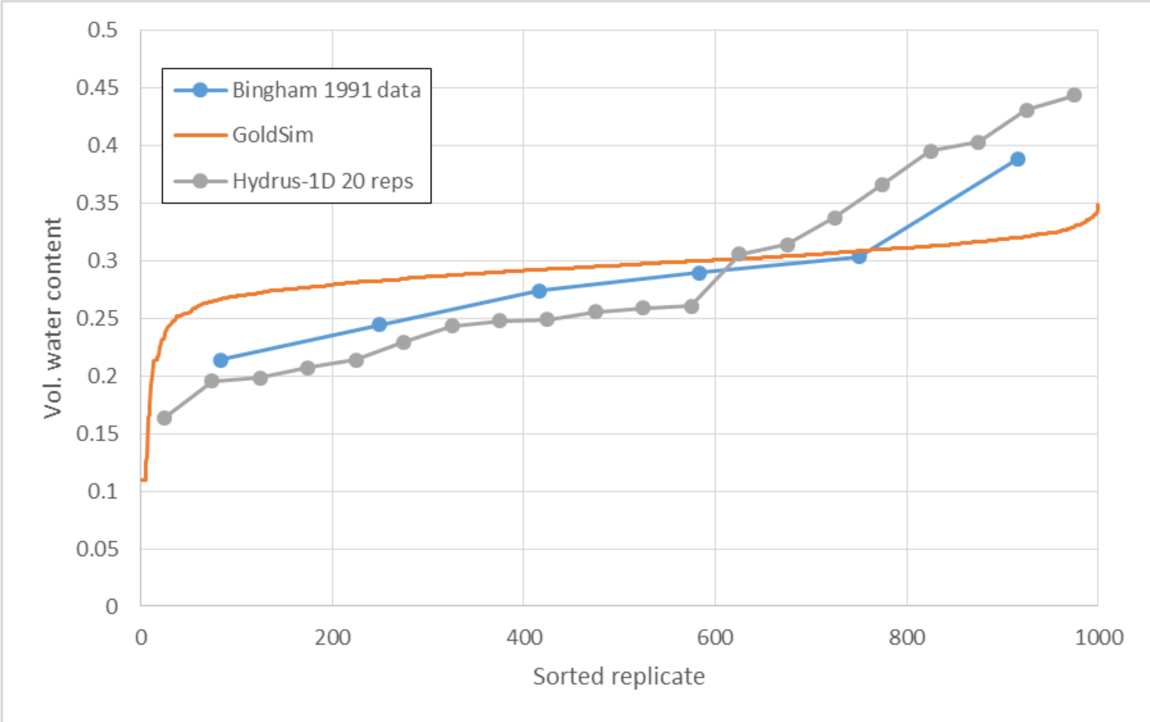



**Figure 14.** Comparison of Bingham (1991) water content data and water content calculated by the GoldSim and HYDRU-1D for the Evaporative Zone layer.

## 10. SUPPLEMENTAL INTERROGATORY COMMENT 10

We believe that there is a typo on p. 42 of Appendix 5; in the statement: "*A normal distribution was fit to the 50th and 99th percentiles* ....", we believe it should be a lognormal distribution.

***EnergySolutions' Response****:* As noted in response to Comment #1, the 50th ad 99th percentiles were used to fit a lognormal distribution, and the value of 0.00432 was then used to truncate the distribution.

## 11. PARAMETER RECOMMENDATION COMMENT

The Division provided Energy*Solutions* with an Excel file "*Clive Hydrus Sensitivity Recommend REV2.xlsx*", which contains suggested or proposed combinations of input values for the HYDRUS runs used to support the Clive DU PA– the contents of the subject Excel file are reproduced here for convenience.

| Layer | Thickness (in) | Saturated Hydraulic Conductivity (cm/s) | | | α (1/kPa) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Typical | High | Low | Typical | High | n | θr | θs | ℓ |
| Surface | 6 | 1.00E-03 | 1.00E-02 | 1.00E-02 | 0.3 | 0.3 | 0.3 | 1.3 | 0.00 | 0.40 | -1 |
| Evaporative Zone | 18 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 0.15 | 0.15 | 0.15 | 1.3 | 0.00 | 0.40 | -1 |
| Frost Protection | 18 | 1.00E-05 | 5.00E-05 | 1.00E-04 | 0.075 | 0.15 | 0.3 | 1.3 | 0.00 | 0.40 | -1 |
| Radon Barrier | 24 | 1.00E-05 | 5.00E-05 | 1.00E-04 | 0.075 | 0.15 | 0.3 | 1.3 | 0.00 | 0.40 | -1 |

**Comments**

1. Added gravel and loosened structure at top surface have compensating effects on sat water content
2. Ensure runoff is < 10% rainfall on annual basis for all simulations. Adjust Ks, alpha to ensure this is case
3. Layers listed top to bottom
4. Report water balance graph for each case
5. ℓ is pore interaction term in van Genuchten-Mualem unsaturated hydraulic conductivity function

**Simulations to Run**

1. Run three cases - LOW, TYPICAL, and HIGH cases using parameters in table.
2. Run one case using TYPICAL alpha,n, theta-s, theta-r, l, and LOW for Ksat for all layers
3. Run one case using TYPICAL alpha,n, theta-s, theta-r, l, and HIGH for Ksat for all layers
4. For each case above, run "warm up" simulation 5 times back to back beforehand using meterological year having annual precipitation closest to long-term average . Use heads from end of this 5 yr simulation as initial conditions for the performance simulation.

***EnergySolutions' Response****:* In general, Energy*Solutions* strongly disagrees with the request of running highly speculative, unsupported, one-off cases suggested in the subject request. This is not consistent with the intent of the Utah regulation nor the meaning or application of a "*sensitivity analysis.*" In practice, an appropriate sensitivity analysis would consider only combinations of input values that are plausibly visible at the site under study. Whereas the concept of plausibility in this context is applied based on available data and professional judgment, the values that are suggested in the subject document (and repeated above) are not plausible for this site.

Energy*Solutions* also disagrees with the intent given that the site will return to natural conditions. In fact, the Division-suggested input values do not match natural conditions, whereas the probability distributions used in the Clive DU PA v1.2 model provide reasonable bounds for site conditions projected into the future given the available information and data.

There are significant limitations in assessing the effects of parameter and conceptual uncertainty using deterministic modeling with specified (discrete) cover designs and bounding transport parameters and assumptions. Any more comprehensive sensitivity analysis for the infiltration modeling should not be based on selective, unrepresentative, and non-systematic changes in physical properties of cover materials. Moving beyond the current model in order to further refine the analysis requires more detailed site-specific data collection. However, the value of any such data collection is highly questionable, since all of the PA model endpoints are insensitive to changes in any of the hydraulic input parameters.

In accordance with well-documented NRC guidance, the probabilistic approach models future conditions by projecting current knowledge/conditions as reasonably as possible while capturing uncertainty in the parameters or assumptions of the model. This is distinctly differentiated from "*conservative*" (i.e., supposedly biased towards safety) modeling that is occasionally seen, typically using point values for parameters (implying a great deal of confidence; i.e., no uncertainty, or conditioning). This type of conservative modeling is often termed "*deterministic*" modeling, and has often been used to support compliance decisions. However, supposed conservatism in parameter estimates (or distributions) is often difficult to judge in fully coupled models in which all transport processes are contained in the same overall PA model. More importantly perhaps, actual conservative dose results from PA models do not support the full capability of a disposal facility, which leads to sub-optimal decisions for disposal of legacy waste and for the nuclear industries that need a disposal option. Conservative, deterministic models may have utility at a "*screening*" level, and they are often useful during probabilistic model building, but they do not provided the full range of information that is necessary for important decisions such as compliance or rule-making (cf., Bogen 1994, Cullen 1994).

Analysis of non-representative, arbitrarily-selected one-off cases that are based on unrealistic conditions easily lead to misinterpretation of the performance of the disposal system.

What is proposed by the Division is not a sensitivity analysis. Rather, the Division proposes an analysis of separate implausible combinations of input parameter values. Some details are provided below:

**Saturated Hydraulic Conductivity (Ks) – Surface Layer**

The surface layer in the ET cover functions as a store and release layer. Proposed values for this layer are 86.4 cm/day for a low value, 864 cm/day for a typical value and 864 cm/day for a high value. The typical and high values proposed exceed the values for the $K_s$ of sand provided in both the Rosetta and Carsel and Parrish databases (712.8 cm/day and 643 cm/day respectively) and are not appropriate for characterizing a silty clay.

These values are also inconsistent with the measurements provided by Benson et al. (2011) for store and release covers. Table 6.6 of Benson et al. (2011) contains geometric mean values of measurements of in-service $K_s$ for store and release covers at 10 sites. The geometric mean values of $K_s$ ranged from 0.65 cm/day to 45.79 cm/day with a geometric mean of all sites of 7.5 cm/day. The proposed low value is an order of magnitude larger and the typical and high values are more than two orders of magnitude larger than the mean of the measured values.

The National Resources Conservation Service (NRCS) Web Soil Survey (WSS) (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm ) provides online access to Soil Reports containing soil property data. The most extensive surface soil type at the Clive Site corresponding to Unit 4 is classified as the Skumpah by NRCS. NRCS assigns $K_s$ values for the upper 5 feet of the Skumpah ranging from 3.6 cm/day to 35 cm/day. These $K_s$ values represent natural conditions. Again, these values are orders of magnitude lower than the proposed values.

**α Values – Surface Layer**

The α values recommended for the low, typical and high cases for the surface layer are 0.3 1/kPa (0.03 1/cm). These values are too high when compared to the values of 0.00295 1/cm and 0.0012 1/cm measured by Bingham Environmental (1991) on two cores taken from Unit 4 at the site.

**All Hydraulic Model Parameters – Frost Protection Layer**

All hydraulic parameter values for the frost protection layer are set to the identical values recommended for the radon barriers. These two materials are quite different, treating them as identical is unrealistic, even after naturalization the frost protection layer will not reach the conditions of the current radon barrier. This would artificially induce more flow through the frost layer, but would not represent the naturalized system.

**Added gravel**

For the HYDRUS simulations a mean value of 0.48 for the porosity of the Unit 4 silty clay used for the surface layer was obtained from the Rosetta database. The effect of the addition of 15 percent gravel to the surface layer on porosity was calculated using ideal packing equations (Koltermann and Gorelick, 1995) giving a value of 0.41. If adding gravel and naturalizing the layer have compensating effects then the saturated water content should have remained 0.48. Their recommended value is 0.4, nearly identical to what we used.

The influence of change in soil structure on saturated hydraulic conductivity of the radon barriers was included in the Clive DU PA model by sampling from a distribution of saturated hydraulic conductivity developed from measurements barrier layers of in service covers (Benson et al.  2011).

**Warm-up Simulations**

The Excel file "*Clive Hydrus Sensitivity Recommend REV2.xlsx*" included requests for "warm up" simulations. Specifically, the request is:

> 4. For each case above, run "warm up" simulation 5 times back to back beforehand using meterological year having annual precipitation closest to long-term average.  Use heads from end of this 5 yr simulation as initial conditions for the performance simulation.

The 20 HYDRUS-1D simulations were conducted with, essentially, a 900-year warm-up period which is a considerably longer time period than the 5 average years requested by the Division. Neptune used a 100-year synthetic record that was repeated 10 times to generate a 1,000-year record of atmospheric boundary conditions. All 20 simulations were run for 1,000 years but only the time series of average water content and infiltration for the last 100 years were used as results. This was done because the initial conditions for all simulations were set to a water potential of -200 cm, which is wetter than steady-state conditions. The long simulation time allowed for equilibration to steady-state. So, essentially there is a 900 year warm up period. Figure 15 shows the time series of infiltration through the ET cover and into the waste zone. It is apparent that even after 900 years, the line is not quite flat, indicating that our infiltration estimates are slightly over-estimated.

Nevertheless, the nine HYDRUS-1D simulations requested by the Division were run and results showing the range from minimum to maximum infiltration (into waste zone), along with the results from the original 20 HYDRUS-1D simulations, are shown in Figure 16. Despite the implementation of the high $K_s$ values requested by the Division, infiltration in the new 9 simulations is generally lower than for the original 20 HYDRUS-1D simulations. This is largely due to setting residual water content to zero, which effectively increases the water holding capacity of each soil layer.

Overall, the Clive DU PA model provides a reasonable range for the input parameters for the hydraulic properties given the currently available data and information, and the HYDRUS runs for the nine additional combinations of single values for inputs adds no further insight.

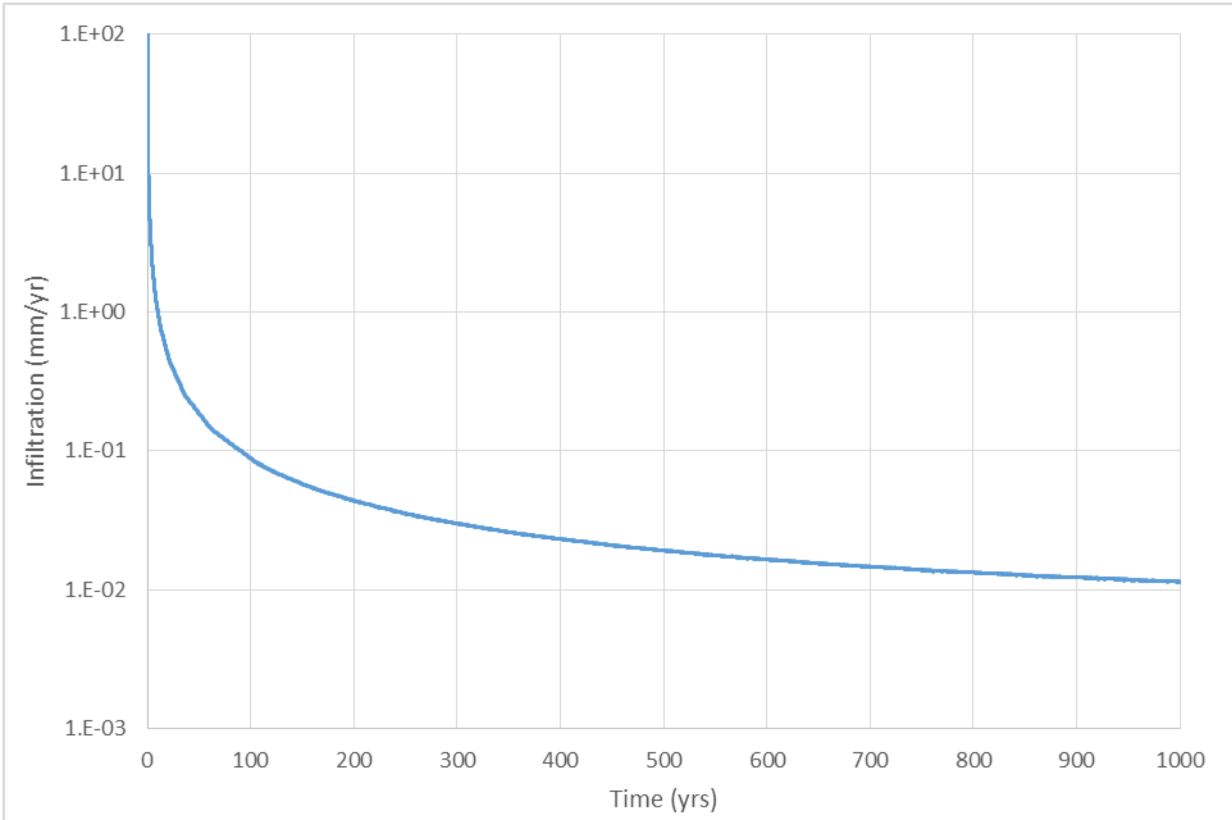



**Figure 15**. Time series of infiltration into the waste zone for one of the 20 HYDRUS-1D simulations.

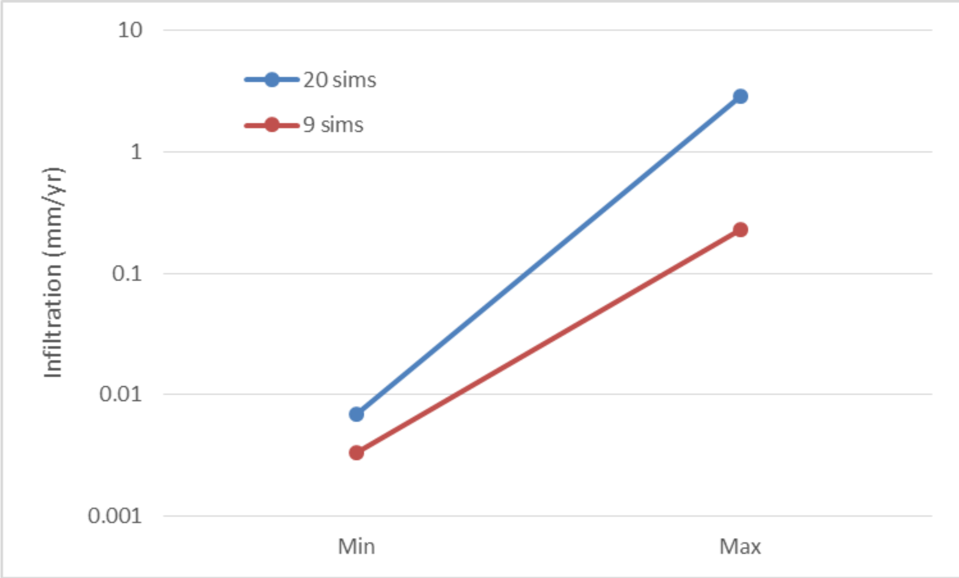



**Figure 16**. Infiltration ranges for the original 20, and new 9 HYDRUS-1D simulations.

## 12. SUPPLEMENTAL INTERROGATORY VOLUME LIMIT COMMENT

Concern was expressed as to the available licensed capacity for material modeled in compliance with Condition 35 of Radioactive Material License UT2300249.

***EnergySolutions' Response***: Energy*Solutions* was granted Radioactive Material License UT2300249 and continues to operate under the conditions of that License and the governing provisions of Utah State Statute 19-3-105. Under Section 10.A and B of that License, Energy*Solutions* "*may receive, store and dispose of licensed material at the Licensee's facility located in Section 32 of Township 1 South and Range 11 West, Tooele County, Utah.*" Subject to types of waste specifically prohibited for disposal (delineated in 19-3-103.7 and siting criteria of 19-3-104), Utah Statute 19-3-105.8(b) specifically states that the "*requirements of Subsections (3)(c) and (d) and Subsection 19-3-104(11) do not apply to (b) a license application for a facility in existence as of December 31, 2006, unless the license application includes an area beyond the facility boundary approved in the license described in Subsection (8)(a).*"

Since its operations have been governed by a License originally issued long before December 31, 2006 and since our current efforts to demonstrate compliance with Condition 35 of that same License do not include expansion to "*an area beyond the facility boundary approved in the license*," Energy*Solutions* is legally authorized to continue to operate within the boundaries already promulgated within its License (i.e., to *receive, store and dispose of licensed material at the Licensee's facility located in Section 32 of Township 1 South and Range 11 West, Tooele County, Utah*.)

Furthermore, Utah Statute 19-3-310 lists as a prerequisite of granting such a License an agreement to "*offset adverse environmental, public health, social, and economic impacts to the State as a whole*," in the event that the disposed material owner is financially unable to provide such. Since a Memorandum of Agreement with DOE, assuming long-term stewardship of the waste material subject to satisfaction of Condition 35 of the License must be successfully executed prior to disposal of such, the State is under no risk of having to financially offset "*adverse environmental, public health, social, and economic impacts to the State as a whole.*"

## 3. SUPPLEMENTAL RESPONSE REFERENCES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## 4. HYDRUS PARAMS AND RESULTS (excel file – electronic copy)